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16. Abstract

An aerodynamic program for steady supersonic linearized potential flow using a higher order panel method has been developed. Boundary surface is divided into planar triangular panels on each of which a linearly varying doublet and a constant or linearly varying source are distributed. From the test run for flows around cones, it is shown that constant source strength on each panel is preferable to that varying linearly when linear distribution is used for the doublet. The arbitrariness of the control points' positions isalso assured by the simulations for the same type of flows. The results for flows around cones and spindle show good agreement with analytical solutions unless the perturbation is too large to satisfy the condition of linearized flow.

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DEVELOPMENT OF A SUPERSONIC COMPUTATIONAL AERODYNAMIC PROGRAM USING THE PANEL METHOD

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1. Introduction.

When the panel method is employed to a supersonic flow, since the fundamental equations are hyperbolic, formulas to be made require some special attention which is different from the attention necessary for a non-compressive flow or subsonic flow, because the fundamental equations are hyperbolic. The following facts are found when developing PAN AIR (Boeing), 1).

(1) Guaranteed Continuity of surface density of doublet and couplings of panels at panel joints are necessary.

(2) Distributions of both a source and a doublet on the panel surface using the Green's equation are necessary.

(1) is for preventing velocity potental from jumping the joints towards lower flow across caracteristic surface. (2) is for preventing propagation of imaginative Mack waves beyond the calculation area (inside domain panel assembly).

Based on the above two discoveries, and the fundamental theory of the panel method, we developed a program using a scheme simpler than the conventional methods, MARCAP (Mitsubishi's Arbitrary Configuration Aerodynamic Program). We will discribe the characterics and outlines of the program and the results of the calculations.

2. Characteristics of the Program.

2.1 Distinctions of Panels and Nodal Points.

Due to the requirement (1), in the supersonic panel method, the high order panel method has to be used, in which the distribution density of doublets on each panel varies depending on the integral functions. When a source or a doublet distributes according to the integral function on the surface of the jointed set of panels, if the value on a finite number of points on the surface is set, the distribution on the assemblies of the panels is set uniformaly. These points are called nodal points. The total number of nodal points does not have to be equal to the total number of panels. The conventional panel methods have lineary distribution (the distribution density is constant on each panel), and as a result, the total numbers of the nodal points and the panels are the same and differences could not be distinquished. For example, in PAN AIR, the total numbers of the panels and the nodal points are forced to match in both a sorce (1st distribution) and a doublet (2nd distribution). As a result, when determining the distribution function, unknown value and the equation value do not match, and a very complicated scheme had to be used such as that aof the least squares or to use the value of a nodal point on a far panel.

In our program, linearly varying doublet and constant and linearly varying distribution sources are distributed. Panels are of a triangular shape and for linearly varying distribution, a nodal point is placed at the vertices of the panels. Therefore, three unknown coeff.s expressed on the distribution function on each panel is determined uniformly at the nodal points. The distribution density at the panel joints is determined at nodal

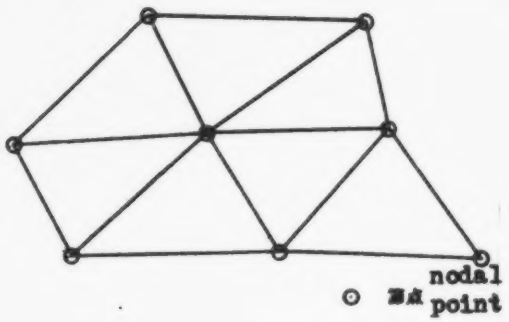


Fig. 1 Panels and Nodal Points

points at the joints so the continuity between the panels are gurarantied. The coupling of the panels is also guaranteed and difinition of mean surface and subpaneling is unnecessary (Fig.1). For a constant distribution, each panel is considered as a nodal point.

2.2 Distinction of Control Points and Panels/Nodal Points.

Converting Prandt-Glauert equation on supersonic flow to functions using Green's equation,

$$\phi(P)=\frac{1}{2\pi}{}^{*}\!\int_{S_w}\mu\frac{\partial}{\partial n_c}\left(\frac{1}{R}\right)dS-\frac{1}{2\pi}\int_{S_w}\frac{\sigma}{R}dS \tag{1}$$

Here,

$$\mu=\phi^{+} \qquad \text{Surface density of a doublet} \tag{2}$$

$$\sigma=\left(\frac{\partial\phi}{\partial n_c}\right)^{+} \qquad \text{Surface dencity of a source} \tag{3}$$

$$R=\sqrt{(x_p-x_Q)^2-B^2(y_p-y_Q)^2-B^2(z_p-z_Q)^2}$$

$$\frac{\partial}{\partial n_c}=-B^2 n_x\frac{\partial}{\partial x_Q}+n_y\frac{\partial}{\partial y_Q}+n_z\frac{\partial}{\partial z_Q}$$

$$B^2=M^2-1$$

Sw: P region on panel assemblies surface S.

${}^{*}\!\int dS$: finite portion of the area.

Q: point on S

M: Main flow Mack no.

n_x, n_y, n_z: elements of normal vector of S.

suffix^{+} : ultimate value approached to S from the calculated area (within the panel).

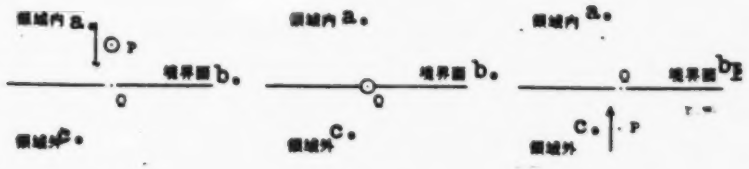
X axis is on the main flow direction.

In Equ.(1), the point P where perturbation velocity potential ϕ is calculated is called the control point. The control points are different from the panels and nodal points. With the distinct differnce in mind, looking at the conventional method, you'll find the next three methods for setting the control points (Fig.2).

(i) Control points are set on those ultimately closest to S from the calculated area.

(ii) Control points are set on the nodal points on S (principal function of Cauchy).

(iii) Control points are set on those ultimately closest to S from outside the calculated area.



(i) (ii) (iii)

a. Within territory b. Boundary surface c. Outside territory

FIg.2 Setting control points

Using those methods, if Equ.(1) is made discrete,

(i),(ii)

$$\sum_{j=1}^{j\max}(\delta_{ij}-a_{ij})\mu_j-\sum_{j'=1}^{j'\max}b_{ij'}\sigma_{j'}=0 \qquad (i=1,2,\cdots i\max) \quad (4a)$$

(iii)

$$\sum_{j=1}^{j\max}a_{ij}\mu_j+\sum_{j'=1}^{j'\max}b_{ij'}\sigma_{j'}=0 \qquad (i=1,2,\cdots i\max) \quad (4b)$$

i is control point no., j, j' are nodal point nos. of doublets and sources. a_{ij}, $b_{ij'}$ are influence coeff.

In methods (i),(ii), control points are either matched with nodal points or approached to those ultimately closest to the nordal points, so that Equ.(2) can be used for deriving Equ.(4a). In other words, if the control points and the nordal points are apart, the left side of Equ. (1) takes the value that is different from μ_j and Equ. (4a) will not be closed on μ_j. In method (iii), the left side is always equal to zero. The equation is closed even when control points are not closest to the nordal points. In other words control points can be set away from nordal points. This will result in the following merits.

When control points are on the boundary line or on the extended line of it, the function indicating the influence coeff. is unique, and requires the special equations. When control points are on the panels or the extended line of them, the calculations are complicated. However when the control points are allowed to be arbitrary positioned, the program becomes much simpler. This could not be true in conventional methods because of the unclear distinctions between control points and nordal points, nordal points and panels.

3. Calculation Scheme.

Morino method 2) is used for setting the boundary conditions. Therefore, the panel assemblies surface S is shaped similar to the panel assembly (Generally not required). Surface density of doublets on each nordal point μ is set positive, and obtained so that the perturbance velocity potential ϕ in the area surrounded by Ss (outside the calclated area) is close to zero. For this, equal number of control points as nordal points at μ are

distributed on the space within the surface. ϕ on each control point is expressed as functions of α, μ and influence coeff. and μ on each nordal point is obtained so that all these ϕ becomes zero. Pressure coeff. on each panel is calculated from u at three nordal points which is the vertex of each panel.

4. Calculation Results.

4.1 Flows Around the Circular Cone.

Fig.3 shows an example of circular cone used in the calculation. Fig.4 shows the results of calculations (pressure distributions of circular cone surface) when angle of incidence $\alpha=0$, half angle $\delta=10^{\circ}$, main flow Mack no. $M=\sqrt{2}$, and a constant and a linearly vary distribution of source σ. For a linearly vary distributions, the tip σ is set to 0. Theoretically, pressure coeff. Cp is constant wherever the position is.

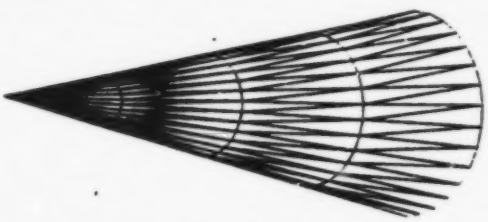


Fig. 3 Panel assemblies (Cone)

Fig. 4 Pressure distribution on spindral surface

Using a linearly distribution on σ has better results. Therefore a linearly distribution is used for calculating the flow around the circular cone.

In the above case, the results of changing the control point positions in 3 places within the cone (pressure distribution on cone surface) are seen in FIg.4. Each control point is positioned so that the influence on the control point which derives from the nodal point

through the surrounding panels should not be zero, because the matrix of influence coeff. a_{ij} in determinant should not become zero. Therefore, this position is perpendicular to the surface of the panel and toward the panel inside by the length d from the nordal point. d, here means;

case 1: $d=0.005\ l_1$

case 2: $d=0.005\ l_1$ (at the tip)

$d=0.2r$ (others)

case 3: $d=0.005\ l_1$ (at the tip)

$d=0.5r$ (others)

l : the length of the lower panel side on the 1st line from the upper flow.

r : diameter of cone at each position.

The results of case 1 and 2 are almost same. This proves that even if the control point is away from the panel, right answers can be obtained. However in case 3, the answer at the 3rd row panel. This is because the influence coeff. matrix loses its superior opposit angle prperty, and accumlates the rounding difference from the reverse determinant calculation. Thus, the control points can be arbitraly set more or less to a point not too far from the nodal points so that the matrix a_{ij} loses its superior opposite angle.

Fug.5,6 show the results of the calculations compared with the analysis reports 3)-6). The calculations are by changing the half cone angle and the Mack no. while the angle of incidence $\alpha = 0°$. Fig.7 shows the surface pressure distribution on the circumference directions compared with the analysis reports 3)-6),

with M=1.5, α=5°, δ=10°. Two kinds of equations are used for the pressure coeff. Cp.

TABLE 1 PRESSURE DISTRIBUTION ON THE CONE SURFACE

($C_p = -2u - (1-M^2)u^2 - v^2 - w^2$)

X	1.3	3.0	5.0	7.0
ケース 1	0.1350	0.1349	0.1349	0.1349
ケース 2	0.1350	0.1350	0.1350	0.1350
ケース 3	0.1350	0.1350	発散 divergence	発散 divergence

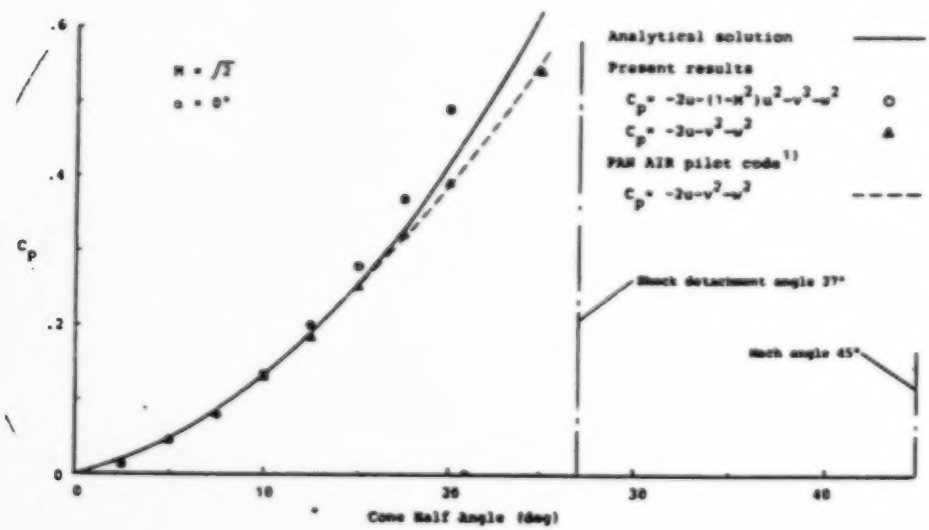


FIg.5 Pressure coeff. on the cone surface

When the perturbation against the main flow is not very large, in other words, within the range where linealization in the equation is propper, the results agree with the reports. The equation $Cp=-2u-v^2-w^2$ shows the better results (u,v,w are each element of the

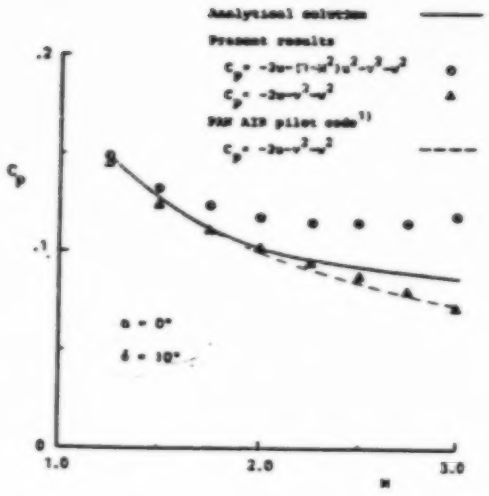


Fig.6 Pressure coeff. on a spindle surface

perturbation velocity). The above results have the trend to follow the same results as the PAN AIR pilot code 1). Thus the equivalent computations seem to be done even though the two use entirely different schemes of computation.

In the above numerical calculations, the time used for the calculation is about 43 sec. per one case (half shape, multiple prescision calculation, IBM4361-5 medium size computer).

4.2 Flows Around Spindle.

Fig.8 shows the pressure distributions compared with the analytical reports. The spindle shape is $r=0.08x^2(1-x)$. It is placed in the flow whoseangle of incidence α is $=0^\circ$ and $M=\sqrt{2}$. Linearly varying distribution of source is usad. It does not use Cp equation and agrees very well with the analytical solutions.

5. Conclusion.

In the high order method which is used when the panel method is applied to the supersonic flow, by making clear distinctions among the concepts of panels, nodal points, and control points, the far better calculation scheme than the conventional method can be found concerning the panel asembly, determination of the determination function, and setting of the control points. The

result of this calculation is as accurate as the conventional way and agrees with the analytical solutions. Control points can be arbitrary set to any position within the panel assembly in the range where it meets the limit of the influence coeff. matrix.

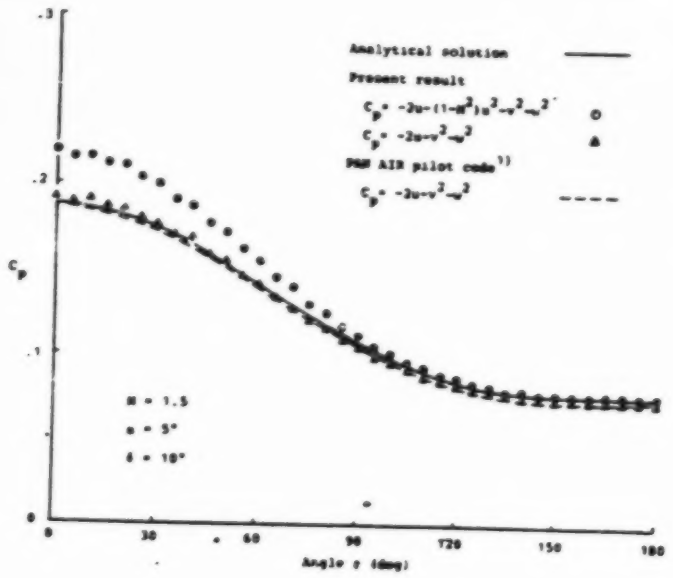


Fig.7 Pressure distribution on a cone surface

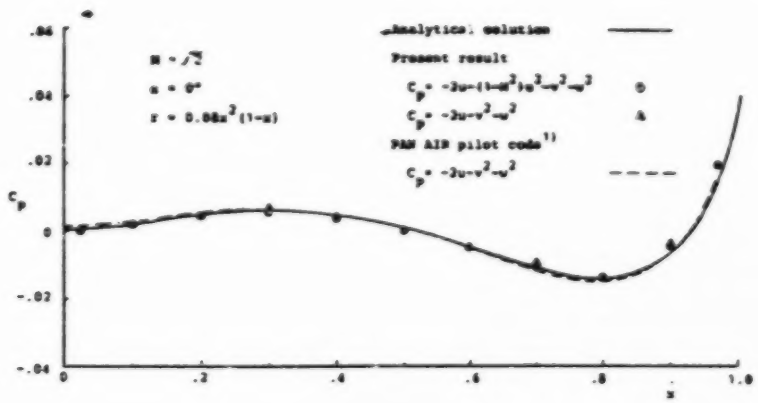


Fig.8 Pressure distribution on a spindle

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